Identifying Battlefield Metrics Through Experimentation

Track: C2 Experimentation

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Identifying Battlefield Metrics Through Experimentation

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Abstract

Command and Control (C2) is a commander's guidance of his/her forces (command) to accomplish a goal or mission while monitoring the directed movements (control). The U.S. Army Research Laboratory's (ARL) Battlespace Decision Support Team (BDST) is exploring methods of evaluating the effectiveness of a commander's plan or course of action (COA). Part of our research involves the task of identifying metrics to rate a COA. We have modified the One Semi-Automated Forces (OneSAF) simulation to track direct fire hits and vehicle damage throughout simulated battles. One completed experiment ran a OneSAF scenario over 200 iterations and captured data. BDST will analyze the collected data to determine its utility in measuring COA effectiveness. Future applications of tools and techniques developed through this and other experiments will assist the commander as real-world battles unfold.

1. Introduction

Command and Control (C2) is a commander's guidance for his/her forces (command) to accomplish a goal or mission while monitoring the directed movements (control). The U.S. Army Research Laboratory's (ARL) Battlespace Decision Support Team (BDST) is exploring methods of evaluating the effectiveness of a commander's plan or course of action (COA). Part of our research involves the task of identifying metrics to rate a COA.

With unlimited resources, a COA could be developed and played out in a field exercise setting. Data could be collected to track casualties, expenditure of supplies, and whether the intended mission was completed. The COA could be changed as necessary to improve the battle outcome and be executed numerous times. However, unlimited resources do not exist. The rising cost of field exercises has coincided with increased military interest in combat simulation. Computerized combat simulations are relatively inexpensive, and COAs can be executed as many times as required. BDST's Course of Action Technology Integration (COATI) project uses combat simulations for battlefield COA evaluation within the military decision making process.

2.0 Killer/Victim Scoreboard Development

Our current work involves using the simulation One Semi-Automated Forces (OneSAF) to examine battle outcomes. OneSAF is developed under the guidance of the U.S. Army Simulation, Training, and Instrumentation Command (STRICOM). ARL has modified the OneSAF code to provide data on direct fire hits and to track entities throughout the battle. The tracking of direct fire hits provides the basis for establishing a Killer/Victim Scoreboard (KVS) capability in OneSAF. The KVS is a preliminary step in the evaluation of a COA's effectiveness.[1]

2.1 OneSAF Modifications

We modified the existing OneSAF software to write a list of all active simulation entities and direct fire events to two separate text files. The file containing the active simulation entities is named with the simulation start time and a "vt" (for vehicle table) extension. This file tracks all battle entities (e.g., dismounted infantry), not just vehicles. The direct fire information file is named with the same time stamp and a "df" (for direct fire) extension.

The vehicle table file contains the OneSAF internal vehicle table (VTAB) and persistent object database (PO) identifications and the vehicle or entity type. See Figure 1 for a sample of the file. This file was created by modifying the *libcr_local.h* and *cr_create.c* programs in OneSAF's *libsrc/libcreate* directory. All active entities are listed in the vehicle table file.

```
VTAB_ID 1059 PO_VEHICLE 100A13 VEHICLE_TYPE vehicle_US_M1A1
VTAB_ID 1047 PO_VEHICLE 100A23 VEHICLE_TYPE vehicle_US_M1A1
VTAB_ID 1050 PO_VEHICLE 100A21 VEHICLE_TYPE vehicle_US_M1A1
VTAB_ID 1036 PO_VEHICLE 100A22 VEHICLE_TYPE vehicle_USSR_T72M
VTAB_ID 1037 PO_VEHICLE 100A21 VEHICLE_TYPE vehicle_USSR_T72M
VTAB_ID 1039 PO_VEHICLE 100A23 VEHICLE_TYPE vehicle_USSR_T72M
```

Figure 1. Sample Entity List

The direct fire file contains the following information for each direct fire hit: the simulation time; the identity of firer and target; the position of firer and target; the ammunition; the range; a kill thermometer (explained in the following paragraph); and result. Direct fire misses and indirect fire hits or misses are currently not recorded, but will be added in the future. See Figure 2 for a sample of one direct fire hit. We obtained the direct fire information by modifying the *dfdam_tables.c* and *dfdam_tick.c* programs in OneSAF's *libsrc/libdfdam* directory.

The kill thermometer determines the outcome of the direct fire. Values are assigned to a continuum of the following probabilities: no damage (Pn), mobility kill (Pm), firepower kill (Pf), mobility and firepower kill (Pmf), and total or catastrophic kill (Pk). When a random number is generated to represent a kill probability, the value is plotted on the kill thermometer. A value that exists between two probabilities indicates the next highest

result. For example, in Figure 2, the kill value is 0.904125. The value for Pmf is 0.90 and 1.0 for Pk. The result of this direct fire will be a total or catastrophic kill (Pk).

```
Time Stamp 997294867
Vehicle ID 1060
Firer ID 1046
Projectile 1143670816
Firer Position:  X = 27091.00  Y = 30013.00  Z = 834.68
Target Position:  X = 23801.81  Y = 29406.17  Z = 827.96
Vehicle 1060: Hit with 1 "munition_USSR_Songster" (0x442b0820)
Comp DFDAM_EXPOSURE_TURRET, angle 40.76 deg Disp 2.775700
ft
Kill Thermometer is: Pk: 1.00, Pmf: 0.90, Pf: 0.90, Pm: 0.70 Pn: 0.70
RANGE  3344.706870
r = 0.904125 kill_type = K
```

Figure 2. One Direct Fire Data Point

2.2 KVS Capability

The KVS enables the expedient collection and evaluation of data from OneSAF simulations. The tabulation of the ammunition with associated outcome results provides insight into a unit's effectiveness. While the KVS is currently being used only for OneSAF simulations, future work will incorporate battlefield monitoring with other simulators.

3.0 Experiment

COATI has placed a great significance on calibrating the course of action process through the use of combat simulations. In fact, the continuation of the COATI project requires an increased understanding of combat simulation: specifically, the collection of simulation data to classify types and meaning. Without this knowledge, we cannot estimate advantages resulting from the incorporation of combat simulation into a tool for the battlefield.

The current experiment is aimed at exercising new capabilities we have incorporated into the OneSAF combat simulation: namely, those of the status data collection suite[2] and the Killer/Victim Scoreboard (KVS). Experimental data will enable us to better understand the operations of OneSAF through an in-depth examination of entity interactions through multiple reenactments of a single combat scenario. Experimental goals include the

development of non-traditional combat metrics, a better understanding of simulation operations, and a method for the depiction of the battle situation at any given time.

3.1 Scenario Development

Driving the experiment was a battle scenario. Our scenario results must range across the set of possible outcomes to enable a better assessment of battle metrics. In support of a mathematically intense treatment of collected data, we developed a scenario that from the same initial conditions produces varied combat outcomes through multiple operations.

Scenario design occurred over a weeklong period. The sensitivity of the OneSAF simulation to vehicle placement, weapons efficiency, armor damage reflection capability, and behavioral options became apparent early in the process. For example, the placement of a vehicle with its flank armor visible to the enemy often resulted in vehicle destruction before it could affect battle outcome in any significant manner. During that time, we ran over 80 repetitions of 42 prototype scenario designs before capturing a scenario that produced a battle with consistently varied outcomes.

The experimental scenario featured a company-sized attack on a prepared defense. The terrain represented typical Southwest Asia desert, reflecting current conflict areas. Since our KVS and data collection capabilities are currently rudimentary, we examined only direct fire entities and combat.

The attack was made from a company position featuring a two-axis advance across a river to seize a vital crossroad located in a town to the south. Enemy forces had time to prepare a defense against these likely attack routes and have placed their vehicles in a multiple defense band layout. If the attacking force could seize the objective below the town, they could deny the use of the town to the enemy, disrupt his communications, and if enough strength were present, be prepared to operate behind his lines.

The attacking force organization consisted of an under-strength company-level unit with M1 main battle tanks. Having some experience with the more modern vehicle performance within OneSAF led us to believe that a more manageable scenario might be constructed using older equipment. In fact, our initial insights were substantiated, as we had to place twice the number of vehicles on the defense to produce acceptable scenario results. We chose 13 older M1 tanks as the attacking force. See Figure 3 for a list of all battle entities.

The M1s were split into two groups. The attack in the East was designed to initially seize the town and then push to the railroad junction in the south. The attack in the West was to initially seize the railroad bridges intact and then push to the railroad junction south of the town. While two different attack routes were traversed by different platoons, the single objective unified the battle at the company level.

Attacking Forces (By attack route):

One Company (-)

East Attacker:	5 M1 Main Battle Tanks	
West Attacker:	8 M1 Main Battle Tanks	

Defending Forces (By defending Battle Position):

One Mixed Battalion (-)

WEST	
Band 1:	2 T-80 Main Battle Tanks
	3 BMP-2 Infantry Fighting Vehicles
Band 2:	2 T-72M Main Battle Tanks
	3 T-72M Main Battle Tanks
	2 T-72M Main Battle Tanks
Band 3:	2 T-72M Main Battle Tanks
Band 4:	2 T-80 Main Battle Tanks
EAST	
Band 1:	3 BMP-2 Infantry Fighting Vehicles
	2 BMP-2 Infantry Fighting Vehicles
Band 2:	3 T-72 Main Battle Tanks
Band 3:	1 T-80 Main Battle Tank
Band 4:	1 T-80 Main Battle Tank

Figure 3. Scenario Table of Entities

The defense was based on more modern Russian equipment and was built on progressive bands of defense designed to break up a coordinated attack on the town. Each band featured a vehicle mix designed to stop the attackers with minimal loss to the defenders. The infantry vehicles were situated in the first band to provide long-range stopping power via their anti-tank missiles, while the tanks in the successive bands provided increased firepower options for both long and close-in fighting.

The layout of the battle is shown in Figure 4. The attack represents an attempt by the friendly commander to flank the town and cause it to be abandoned by controlling key terrain to the south. In actuality, the defensive posture causes this attack to be a frontal assault against a prepared defense along both attack routes. The attacker faces the worst-case scenario with an unfavorable combat power ratio. Specifically, there are two defenders for every attacker, all of whom are oriented in favorable aspect for the attack.

The battle can be split into two interlocking parts: the eastern battle through the town and the western battle to flank the town. These battles are sufficiently geographically spread to be independent, until the latter stages when the eastern attack progresses to engage western defense bands 3 and 4. In an optimal situation for the attacker, this occurs as the

eastern forces reach the company objective. Both attacks feature a contested river crossing, an unfavorable mission for the attacker, early in the battle. The rest of the battle occurs on flat ground with the exception of the town in the western attack.

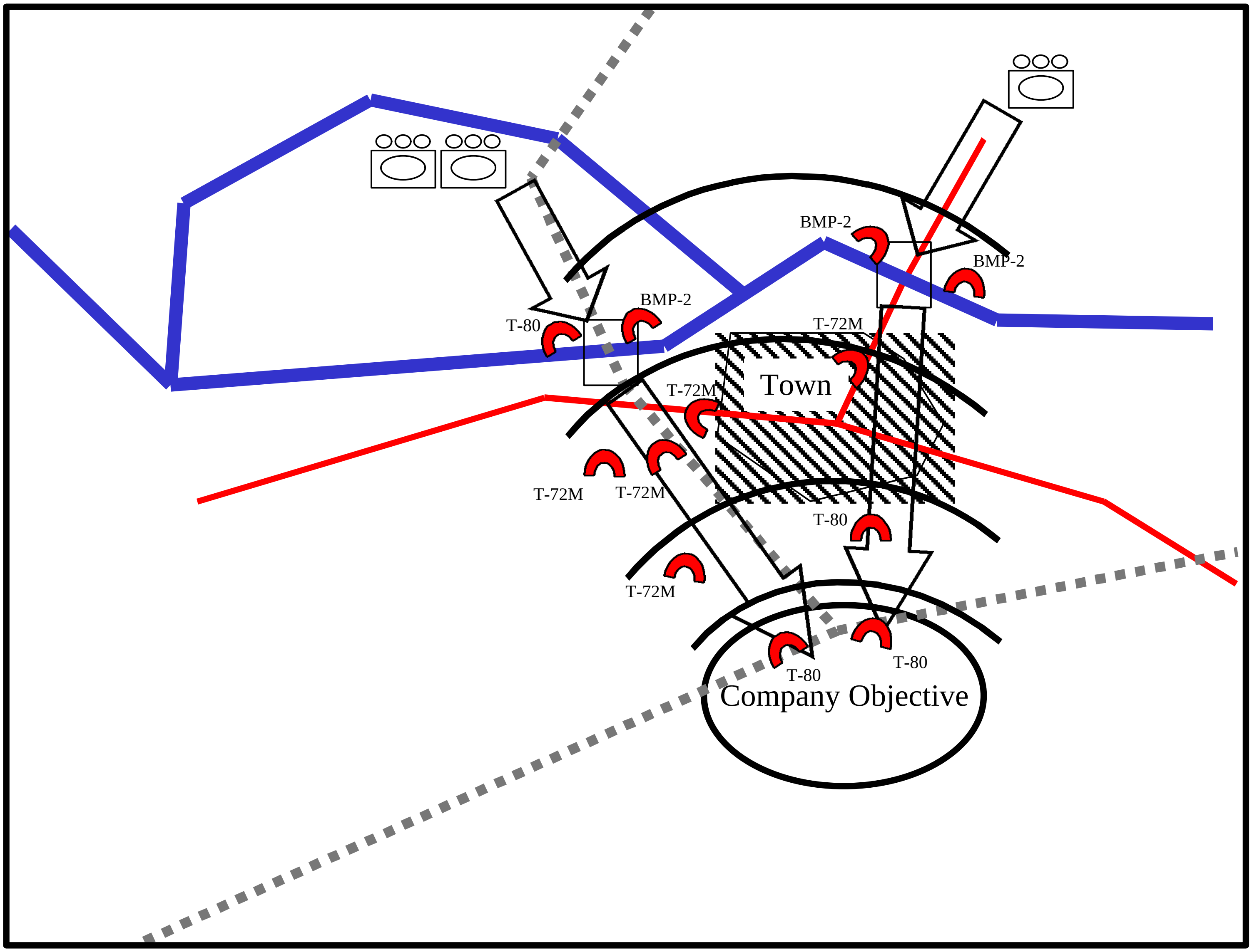

Figure 4. Battle Layout

The bands of defense provide a useful metric to gage the battle progress. We could easily track the progress of the battle by noting the number of bands penetrated by the attacker. We created a scoring system in which the basis value of each attacking vehicle, ¼ point, was multiplied by the number of the band penetrated to show terrain control. (A ¼ point was used for each vehicle so that a platoon equals one point.) The total score for the scenario is the summation of each vehicle’s modified point value. Further, since

capability for continued operations must be considered, if no attacking vehicle remained operational after the objective was occupied, then the entire score was halved.

The scenario score could range from a low of zero, when all attackers are eliminated before the penetration of band 1, to a high of 13, when all attacking vehicles occupy the objective fully operational. To date, our scores have ranged from a low of 1.375 to a high of 13. The measure indicates the scenario can provide a rich set of data showcasing the diversity of OneSAF behaviors and force interactions.

3.2 Execution

Following the scenario development, our next step was the actual experiment. We ran OneSAF on multiple systems to allow maximum usage. All OneSAF scenarios were executed on either SGI® or Sun Microsystems® computers. We executed 231 scenarios over a period of three months. A central repository was created for data storage and subsequent processing. The actual time for each scenario execution varied from 28 minutes to more than 90 minutes. BDST personnel supervised all scenario runs, ensuring accurate data collection and providing insights on battle outcome.

3.3 Data Tabulation and Analysis

During the scenario execution period, we began work on developing the software to parse and tabulate the large amount of data. The software was developed using the Bourne Shell Script language. This provided a way for any UNIX system to run the data tabulation. We identified a set of 435 data fields for future analysis. Data was collected at three time slices during the battle when 10%, 25%, and 40% of the M1 ammunition had been expended. The data fields included vehicle appearance, number of rounds expended, average range for ammunition used, number of side impacts, and distance to the objective for the three M1 platoons at each time. Also information was collected at the end of the simulation for number of M1s on the objective, number of M1s undamaged, and the final score. The shell scripts collect the required fields in an ASCII file for input to multiple statistical analysis software packages.

Data collection led us to the hypothesis that parameterization of the important factors of a battle is possible. That is breaking the battle into homogeneous pieces, we could create a pool of battlefield parameters from which to build composite evaluation metrics. Each data item collected during the experiment qualified as a parameter. Our endeavors now turned to the establishment of a process that might result in descriptive battle metrics.

Each of the data items was broken down into a quantitative bar graph noting the range of outcomes of the data point and the number of times that particular outcome was observed over the range of the main response variable, namely friendly force success or failure. We set the conditions of a friendly force success to be four undamaged M1 tanks positioned on the objective at the conclusion of the battle.

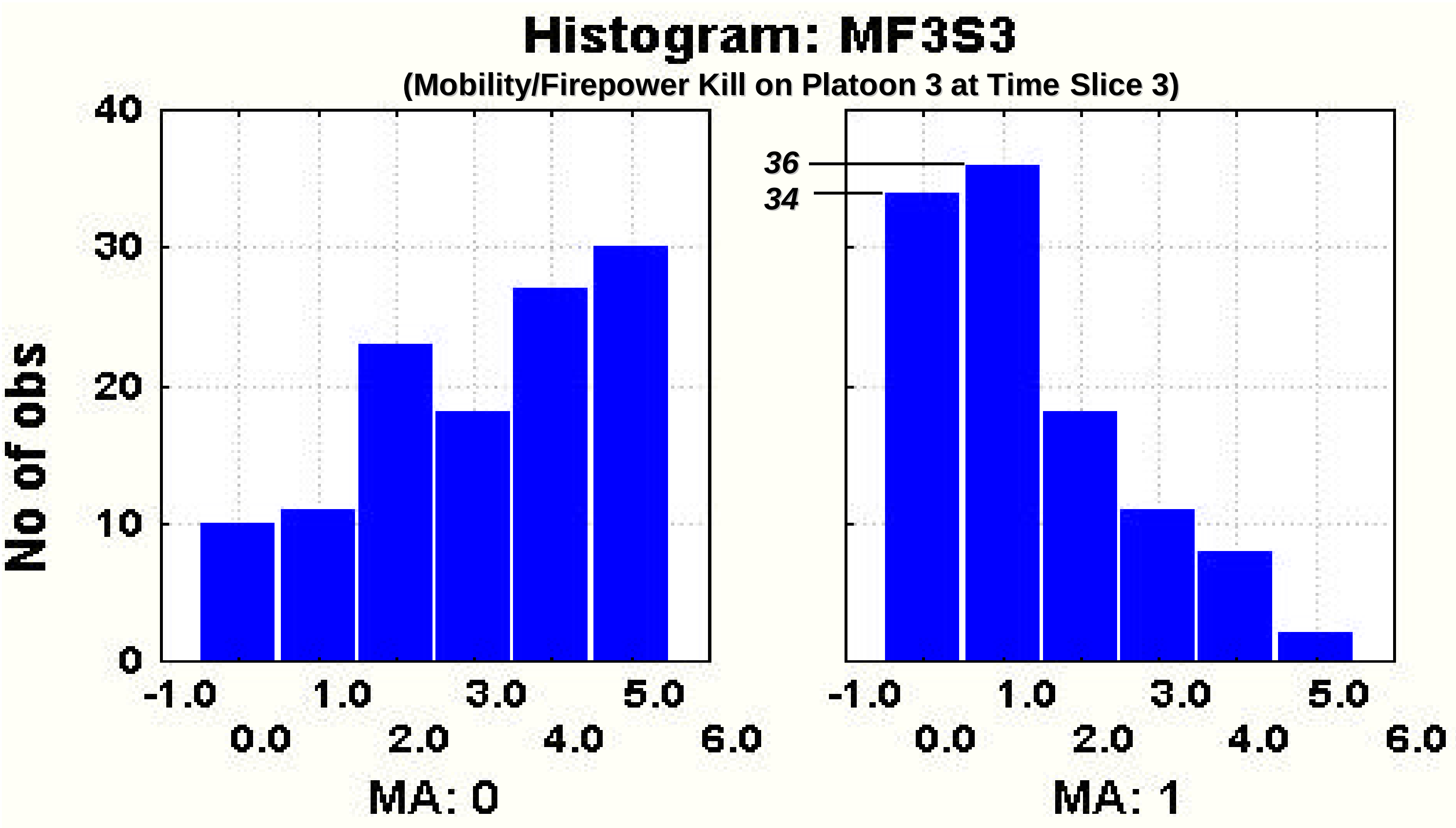

Figure 5: This figure shows a battlefield parameter histogram of mission accomplishment (MA) observations (Y-axis) for friendly force success (1) and failure (0) when the variable MF3S3 is equal to each strength level (X-axis).

While we charted all of the parameters within the data, only those with a significant correlation to the observed battle end-state became part of a metric. Figure 5 shows an example histogram that begins the process. The bars represent the battlefield parameter of vehicles that have sustained mobility and firepower damage within the third friendly platoon (designated platoon 3 and found on the eastern leg of the battle) by time slice three (denoted as 40% of M1 ammunition usage). The number of observations reflecting success with the loss of zero or one vehicle from this platoon (first two bars of the MA:1 chart, 70 out of 110) is significant. Likewise, the last four bars of the failure case (MA: 0) points to a significant number of battle losses when platoon three is severely damaged (2 or more vehicles lost). This parameter suggests that the success of platoon three is critical to the overall success of the battle.

We examined the entire data set for each time slice to determine interactions between parameters like MF3S3 shown in figure 5. Interacting parameters suggest a composite metric. One statistical method that reveals these interactions is the Classification And Regression Tree (CART). An example of a CART appears in Figure 6. This CART begins with a node representing the observed success and failure in the scenario, a near even split between the two end conditions; the number of successful observations

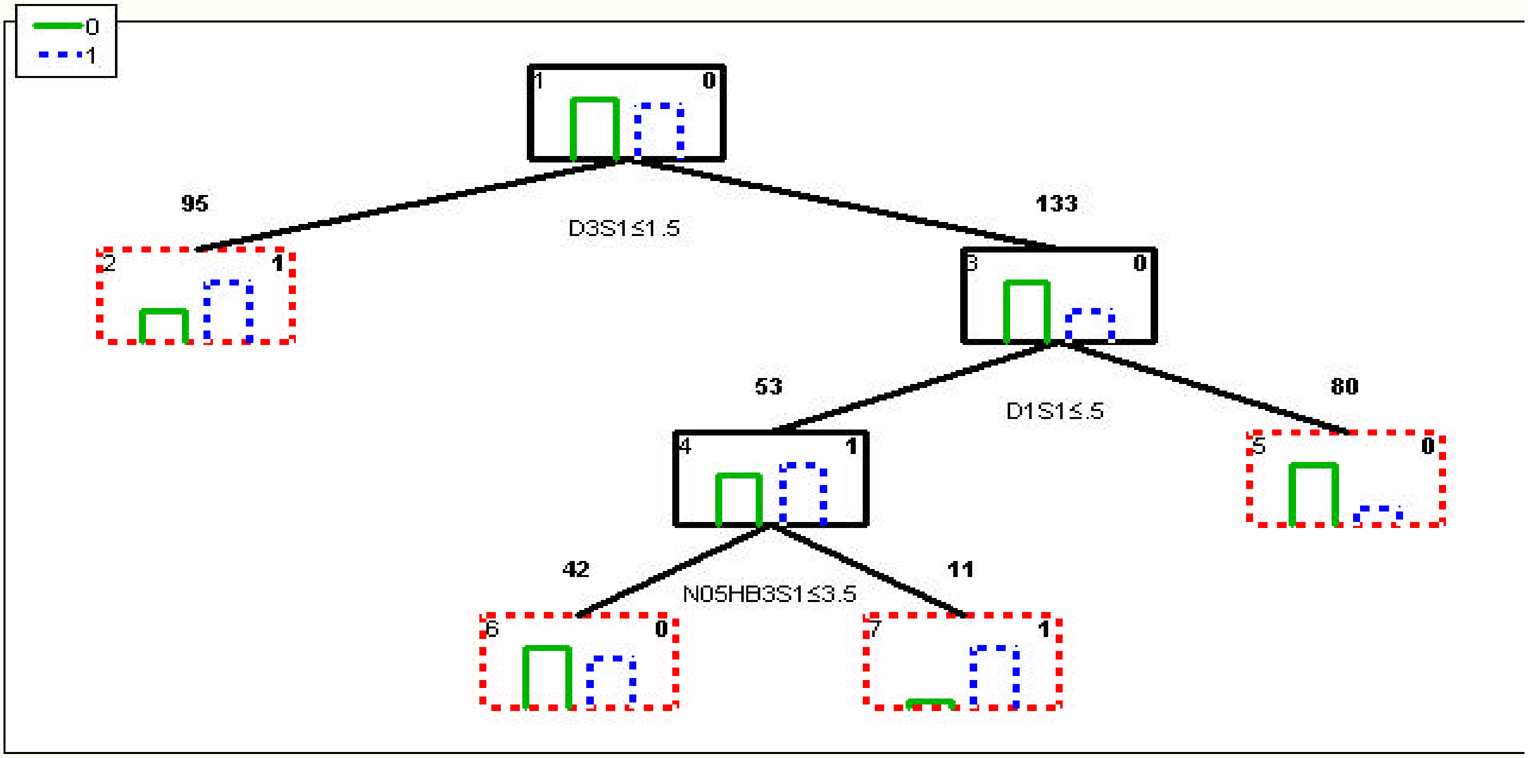

Figure 6: This figure shows an example Classification and Regression Tree for a composite metric consisting of 3 battlefield parameters; each battlefield parameter causes a split in the tree that yields a more pure classification in the red dashed boxes. The green bar represents mission failure and the blue dashed bar represents mission successes classified in each tree box (or node). The bar heights represent number of observations for each case (higher meaning more observations).

represented by the dashed blue bar and the number of failures represented by the solid green bar. Using the classification bar charting method, the first parameter of significance is D3S1. This translated into the parameter representing, "damage done to platoon 3 during time slice 1." The condition that one or less vehicles damaged causes the creation of two new tree nodes. The left-hand node shows the classification of 95 observations as successful with an error indicated by the green bar (failures). The resulting node shows about a 60% correct classification of success given the first condition. The right-hand node shows perhaps a slightly better chance of successfully classifying a failure.

Black nodes are intermediate steps in the classification process while red nodes indicate a methodology product. The process further classifies intermediate nodes by applying more parameters. Thus, the 133 observations on the right-hand node are broken into 80 on the extreme right that have nearly an 80% classification rate of failure and 53 observations on the left-hand side that have about a 55% classification rate of success. The parameter used in the further classification is D1S1 or "Damage done to platoon 1 during time slice 1." The condition indicates that platoon 1 received no damage.

To show that non-traditional metrics may make an operation difference, the final split occurred on the N05HB3S1 parameter. This translates into, "Number of 105mm HEAT (High Explosive, Anti-Tank) munitions damaging BMP (enemy infantry fighting vehicles) shot by platoon 3 during time slice 1." The condition indicates three or less shots. Since the BMPs are met by platoon three in the first part of the battle, the interpretation of battlefield conditions suggests that if friendly platoon three can eliminate the BMP vehicles with a minimum usage of 105mm HEAT rounds there is a greater chance of success. In other words, there will be more 105mm available for use against targets later in the battle.

Execution time (in minutes)	Distance Traveled (in meters)	Correct Classification Percentages		
		Success	Failure	Overall
5 1/2	2000	69	71	70
10 ½	4000	77	82	80
20	5800	82	88	85

Table 1: This table shows the results of the initial composite metric development with the correctness of the classification procedures given at the three chosen time slices during the simulate battle.

By comparing parameters (See Table 1) through the methods described above, we have achieved the following classifications. During the first time slice, roughly 10% of ammunition usage, about five minutes into the nearly hour-long battle, we classified a win to an accuracy of 67% while a loss to an accuracy of 71%. Similarly, for time slice 2, 10 minutes into the battle, we classified a win to an accuracy of 77% and a loss to an accuracy of 82%. Again, in time slice 3, 20 minutes into the battle, we classified a win to an accuracy of 82% and a loss to an accuracy of 88%.

It is our hope that we can give commanders a battlefield edge by indicating important parameters and a time span during which these are significant to battle outcome. By including statistical analyses during planning, the commander's staff might better prepare their units for an upcoming battle. Items like increasing the number of 105mm HEAT rounds for platoon three or increasing the forces moving along the eastern axis of advance should improve the chances of victory. We plan to perform experimentation to determine the meaningfulness of our findings in the near future.

4.0 Conclusion

As we complete the OneSAF KVS experiment, BDST will focus on the development of improved combat metrics. Traditional land combat metrics rely on two main features, force attrition, and objective attainment. While these metrics do tell us about the combat, they do not indicate everything necessary to evaluate a COA. Other relevant factors, such as a unit's combat effectiveness or supply status, may be helpful in determining important aspects of a battle outcome. A battle is often part of a continuing campaign, so an understanding of ammunition effectiveness or the outcome of applied tactics and techniques could also determine a COA's efficiency.

The KVS was designed for data collection to support the development of non-traditional metrics. Information collected through the application of a KVS will provide a wealth of data for the computation of such new metrics. While the use of the OneSAF KVS is only a beginning step towards establishing new metrics to determine a COA's efficiency, it is a step in the right direction. Future applications of tools and techniques developed through these and similar experiments will assist commanders as real-world battles unfold.

References

[1] Heilman, Eric G., and Janet F. O'May, *OneSAF Killer/Victim Scoreboard Capability*, US Army Research Laboratory Technical Report, 2002 (currently in publishing).

[2] O'May, Janet et al., "Effects of Combat Simulation Variance on Course of Action Development," Proceedings of the 6th International Command and Control Research and Technology Symposium, 2001.

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Acronyms

ARL	Army Research Laboratory
BDST	Battlespace Decision Support Team
C2	Command and Control
CART	Classification and Regression Tree
COA	Course of Action
COAA	Course of Action Analysis
COATI	Course of Action Technology Integration
D1S1	Damage platoon 1 time Slice 1
D3S1	Damage platoon 3 time Slice 3
HEAT	High Explosive, Anti-Tank
KVS	Killer/Victim Scoreboard
MA	Mission Accomplishment
MF3S3	Mobility/Firepower damage platoon 3 time Slice 3
N05HB3S1	Number 105mm HEAT damaging BMP platoon 3 time Slice 1
PO	Persistent Object
OneSAF	One Semi-Automated Forces
STRICOM	Simulation, Training, and Instrumentation Command
VTAB	Vehicle Table